

WHAT IS CLAIMED IS:

1. A spin-valve thin-film magnetic element comprising:
  - a substrate;
  - an antiferromagnetic layer;
  - a pinned magnetic layer in contact with the antiferromagnetic layer, the magnetization vector of the pinned magnetic layer being pinned by an exchange coupling magnetic field between the antiferromagnetic layer and the pinned magnetic layer;
  - a nonmagnetic conductive layer in contact with the pinned magnetic layer;
  - a free magnetic layer in contact with the nonmagnetic conductive layer;
  - an exchange bias layer for magnetizing the free magnetic layer so that the magnetization vector of the free magnetic layer is substantially orthogonal to the magnetization vector of the pinned magnetic layer;
  - a pair of electrode layers for supplying a sensing current to the pinned magnetic layer, the nonmagnetic conductive layer, and the free magnetic layer; and
  - a mean-free-path-extending layer provided between the free magnetic layer and the exchange bias layer for controlling the magnitude of an exchange coupling magnetic field between the free magnetic layer and the exchange bias layer and for extending the mean free path of conduction electrons.

2. A spin-valve thin-film magnetic element according to claim 1, wherein the mean-free-path-extending layer includes a back layer comprising a nonmagnetic conductive material.

3. A spin-valve thin-film magnetic element according to claim 2, wherein the back layer has a thickness in the range of 5 to 30 angstroms.

4. A spin-valve thin-film magnetic element according to claim 2, wherein the back layer comprises at least one element selected from the group consisting of Au, Ag, and Cu.

5. A spin-valve thin-film magnetic element according to claim 3, wherein the back layer comprises at least one element selected from the group consisting of Au, Ag, and Cu.

6. A spin-valve thin-film magnetic element according to claim 5, wherein the back layer comprises Cu and has a thickness in the range of 15 to 25 angstroms.

7. A spin-valve thin-film magnetic element according to claim 1, wherein the mean-free-path-extending layer includes a mirror reflective layer comprising an insulating material.

8. A spin-valve thin-film magnetic element according to claim 2, wherein the mean-free-path-extending layer includes a mirror reflective layer comprising an insulating material disposed between the exchange bias layer and the back layer.

9. A spin-valve thin-film magnetic element according to claim 7, wherein the mirror reflective layer has a thickness in the range of 5 to 500 angstroms.

10. A spin-valve thin-film magnetic element according to claim 8, wherein the total thickness of the mirror reflective layer and the back layer is in the range of 5 to 500 angstroms.

11. A spin-valve thin-film magnetic element according to claim 7, wherein the mirror reflective layer comprises a substance which can form a high energy gap having a high probability of mirror reflection maintaining the spin state of the conduction electrons.

12. A spin-valve thin-film magnetic element according to claim 8, wherein the mirror reflective layer comprises a substance which can form a high energy gap having a high probability of mirror reflection maintaining the spin state of the conduction electrons.

13. A spin-valve thin-film magnetic element according to claim 9, wherein the mirror reflective layer comprises a substance which can form a high energy gap having a high probability of mirror reflection maintaining the spin state of the conduction electrons.

14. A spin-valve thin-film magnetic element according to claim 10, wherein the mirror reflective layer comprises a substance which can form a high energy gap having a high probability of mirror reflection maintaining the spin state of the conduction electrons.

15. A spin-valve thin-film magnetic element according to claim 1, wherein the antiferromagnetic layer, the pinned magnetic layer, the nonmagnetic conductive layer, the free magnetic layer, and the exchange bias layer are deposited in that order on the substrate.

16. A spin-valve thin-film magnetic element according to claim 1, wherein the exchange bias layer, the free magnetic layer, the nonmagnetic conductive layer, the pinned magnetic layer, and the antiferromagnetic layer are deposited in that order on the substrate.

17. A spin-valve thin-film magnetic element according to claim 1, wherein the pair of electrode layers lie at least on two sides in the planar direction of the free

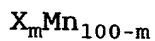
magnetic layer.

18. A spin-valve thin-film magnetic element according to claim 17, wherein the pair of electrode layers lie at least on two sides in the planar direction of the free magnetic layer, the nonmagnetic conductive layer, and the pinned magnetic layer.

19. A spin-valve thin-film magnetic element according to claim 1, wherein at least one of the pinned magnetic layer and the free magnetic layer is divided into two sublayers by a nonmagnetic interlayer, said sublayers being in a ferri-magnetic state in which the magnetization vectors thereof are antiparallel to each other.

20. A spin-valve thin-film magnetic element according to claim 1, wherein each of the antiferromagnetic layer and the exchange bias layer comprises an alloy comprising Mn and at least one element selected from the group consisting of Pt, Pd, Ir, Rh, Ru, Os, Au, Ag, Cr, Ni, Ne, Ar, Xe, and Kr.

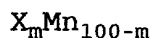
21. A spin-valve thin-film magnetic element according to claim 20, wherein the antiferromagnetic layer comprises an alloy represented by the following formula:



wherein X is at least one element selected from the group consisting of Pt, Pd, Ir, Rh, Ru, and Os, and the subscript

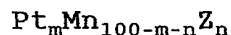
m is in the range of 48 atomic percent  $\leq m \leq 60$  atomic percent.

22. A spin-valve thin-film magnetic element according to claim 20, wherein the exchange bias layer comprises an alloy represented by the following formula:



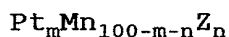
wherein X is at least one element selected from the group consisting of Pt, Pd, Ir, Rh, Ru, and Os, and the subscript m is in the range of 52 atomic percent  $\leq m \leq 60$  atomic percent.

23. A spin-valve thin-film magnetic element according to claim 20, wherein the antiferromagnetic layer comprises an alloy represented by the following formula:



wherein Z is at least one element selected from the group consisting of Pd, Ir, Rh, Ru, and Os, and the subscripts m and n are in the ranges of 48 atomic percent  $\leq m + n \leq 60$  atomic percent and 0.2 atomic percent  $\leq n \leq 40$  atomic percent.

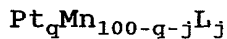
24. A spin-valve thin-film magnetic element according to claim 20, wherein the exchange bias layer comprises an alloy represented by the following formula:



wherein Z is at least one element selected from the group

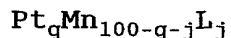
consisting of Pd, Ir, Rh, Ru, and Os, and the subscripts m and n are in the ranges of 52 atomic percent  $\leq m + n \leq 60$  atomic percent and 0.2 atomic percent  $\leq n \leq 40$  atomic percent.

25. A spin-valve thin-film magnetic element according to claim 20, wherein the antiferromagnetic layer comprises an alloy represented by the following formula:



wherein L is at least one element selected from the group consisting of Au, Ag, Cr, Ni, Ne, Ar, Xe, and Kr, and the subscripts q and j are in the ranges of 48 atomic percent  $\leq q + j \leq 60$  atomic percent and 0.2 atomic percent  $\leq j \leq 10$  atomic percent.

26. A spin-valve thin-film magnetic element according to claim 20, wherein the exchange bias layer comprises an alloy represented by the following formula:



wherein L is at least one element selected from the group consisting of Au, Ag, Cr, Ni, Ne, Ar, Xe, and Kr, and the subscripts q and j are in the ranges of 52 atomic percent  $\leq q + j \leq 60$  atomic percent and 0.2 atomic percent  $\leq j \leq 10$  atomic percent.

27. A method for making a spin-valve thin-film magnetic element comprising the steps of:

depositing an antiferromagnetic layer, a pinned magnetic layer, a nonmagnetic conductive layer, a free magnetic layer, a mean-free-path-extending layer, and an exchange bias layer on a substrate;

annealing these layers at a first annealing temperature while applying a first magnetic field in a direction perpendicular to the track width direction to generate an exchange anisotropic magnetic field in the antiferromagnetic layer and another exchange anisotropic magnetic field in the exchange bias layer, the exchange anisotropic magnetic field of the antiferromagnetic layer being larger than the exchange anisotropic magnetic field of the exchange bias layer, so as to pin the magnetization vector of the pinned magnetic layer and the magnetization vector of the free magnetic layer in the same direction;

annealing these layers at a second annealing temperature higher than the first annealing temperature while applying a second magnetic field in the track width direction, the second magnetic field being larger than the exchange anisotropic magnetic field of the exchange bias layer and smaller than the exchange anisotropic magnetic field of the antiferromagnetic layer, to impart a bias magnetic field substantially orthogonal to the magnetization vector of the pinned magnetic layer to the free magnetic layer; and

forming electrode layers for applying a sensing current to the free magnetic layer.



28. A method for making a spin-valve thin-film magnetic element comprising the steps of:

depositing an exchange bias layer, a mean-free-path-extending layer, a free magnetic layer, a nonmagnetic conductive layer, a pinned magnetic layer, and an antiferromagnetic layer on a substrate;

annealing these layers at a first annealing temperature while applying a first magnetic field in the track width direction to generate an exchange anisotropic magnetic field in the antiferromagnetic layer and another exchange anisotropic magnetic field in the exchange bias layer, the exchange anisotropic magnetic field of the exchange bias layer being larger than the exchange anisotropic magnetic field of the antiferromagnetic layer, so as to pin the magnetization vector of the pinned magnetic layer and the magnetization vector of the free magnetic layer in the same direction;

annealing these layers at a second annealing temperature higher than the first annealing temperature while applying a second magnetic field in a direction perpendicular to the track width direction, the second magnetic field being larger than the exchange anisotropic magnetic field of the antiferromagnetic layer and smaller than the exchange anisotropic magnetic field of the exchange bias layer, to impart an exchange coupling magnetic field substantially orthogonal to the magnetization vector of the

free magnetic layer to the pinned magnetic layer; and

forming electrode layers for applying a sensing current to the free magnetic layer.

29. A method for making a spin-valve thin-film magnetic element according to claim 27, wherein each of the antiferromagnetic layer and the exchange bias layer comprises an alloy comprising Mn and at least one element selected from the group consisting of Pt, Pd, Ir, Rh, Ru, Os, Au, Ag, Cr, Ni, Ne, Ar, Xe, and Kr.

30. A method for making a spin-valve thin-film magnetic element according to claim 27, wherein the first annealing temperature is in the range of 220°C to 240°C.

31. A method for making a spin-valve thin-film magnetic element according to claim 27, wherein the second annealing temperature is in the range of 250°C to 270°C.

32. A method for making a spin-valve thin-film magnetic element according to claim 30, wherein the second annealing temperature is in the range of 250°C to 270°C.

33. A method for making a spin-valve thin-film magnetic element according to claim 28, wherein each of the antiferromagnetic layer and the exchange bias layer comprises an alloy comprising Mn and at least one element

selected from the group consisting of Pt, Pd, Ir, Rh, Ru, Os, Au, Ag, Cr, Ni, Ne, Ar, Xe, and Kr.

34. A method for making a spin-valve thin-film magnetic element according to claim 28, wherein the first annealing temperature is in the range of 220°C to 240°C.

35. A method for making a spin-valve thin-film magnetic element according to claim 28, wherein the second annealing temperature is in the range of 250°C to 270°C.

36. A method for making a spin-valve thin-film magnetic element according to claim 34, wherein the second annealing temperature is in the range of 250°C to 270°C.